Institut für Erdmessung

On the influence of the troposphere on GNSS-based distance metrology: modeling and experiments

- 1st Workshop on Metrology for long distance surveying -

Session IIa: GNSS-based distance metrology - understanding uncertainty contributions

Institut für Erdmessung

Leibniz Universität Hannover

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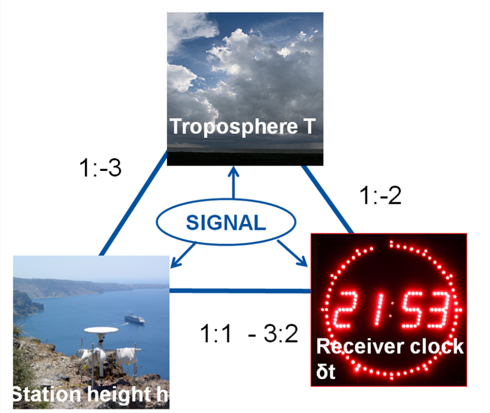
Overview

1. **Concept of reducing tropospheric refraction**
   - Motivation and issues
   - Concept for modeling the troposphere
   - Mathematical issue
2. **Setup for scenarios**
3. **Scenarios for combining networks**
   - Scenario 1: two local stations whereby one is connected to a reference station
   - Scenario 2: two local stations connected to unique reference station
   - Scenario 3: two local stations connected to two reference stations
4. **Summary and outlook**

GNSS observation modeling | impact of troposphere



Bermuda triangle

- high correlations between certain parameters in GNSS observation modeling
- 1 mm deviation in tropospheric delay relates to -3 mm in up-component

Concept for correcting local ties: Issues

Discrepancy [mm]	GPS-VLBI [%]	GPS-SLR [%]	GPS-DORIS [%]
<6	47	43	34
6-10	24	29	12
>10	**29**	**28**	**54**

Local ties

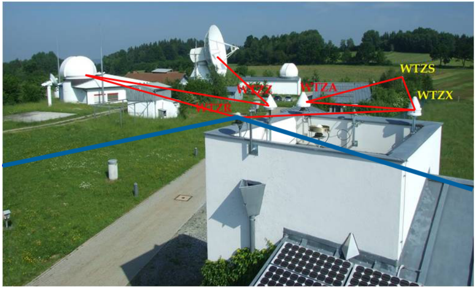
- table shows local tie discrepancies of ITRF, [Altamimi et al., 2011]
- mean value of combinations shows for 37% discrepancies of > 10 mm

Issues

- mixed observation types between **local** and **global** baselines
- discrepancies w.r.t. terrestrial survey

short baseline: < 10 km

long baselines: ≥ 10 km



Fundamental station Wettzell, Bad Koetzing, Germnay

Classification of coordinate variations

$$\mathbf{\Delta\hat{x}} = \begin{bmatrix} \Delta\mathrm{N} \\ \Delta\mathrm{E} \\ \Delta\mathrm{U} \\ c \cdot \delta\mathrm{t} \\ \vdots \end{bmatrix} = \mathbf{(A^TPA)^{-1}A^TP\,\Delta l} = \mathbf{K\Delta l} \qquad (1)$$

mathematical effect

Dimension and elements of **K** change if additional tropospheric parameters are estimated.

physical effect

Matrix **K** stays unchanged, values of Δ**l** change due to different

- frequencies (L_1, L_2,...)
- linear combinations (L_3,...)
- environmental situations
- antennas

Concept for correcting local ties: mathematical effect

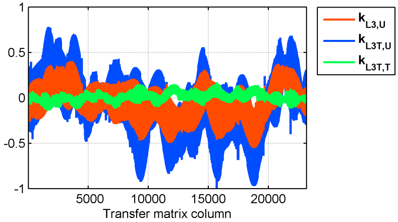
Basic observation by analysing transfer matrix K, [Schön, 2007]

- mathematical effect leads to *apparent* height deviation
- ratio δ_U^T or (ΔU/ΔT) is constant
- values ($\delta_U^T \in$ [-3.5;-3]) depend on applied cutoff angle
- ratio of lines in matrix **K** shows same behavior
- applying correction

$$\boxed{\Delta h'_{L_3T} = \Delta h_{L_3T} - \delta_U^T \cdot \Delta T}$$

	ΔN [mm]	ΔE [mm]	ΔU [mm]	Δ T [mm]
L_3	0.54	-0.24	**-1.76**	-
L_3T	0.61	-0.26	**-3.78**	**0.64**

Table: Different analysis methods for a 20 m baseline.



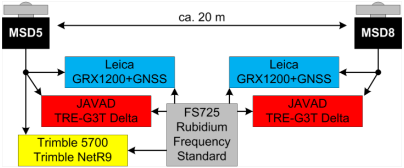
Setup on laboratory network of Institut für Erdmessung (IfE)

Measurement configuration

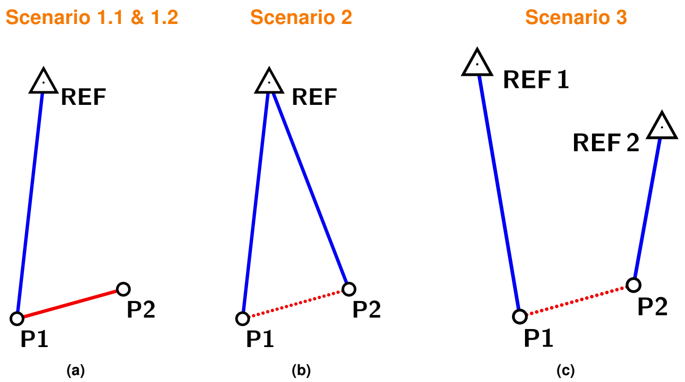
- 5×24 h sessions from 25.11.-30.11.2011 (DOY 339-341)
- absolute calibrated GNSS antenna (Leica AT504GG)
- Leica GRX1200+GNSS receivers on both stations

GPS analysis

- Bernese 5.0 / 5.2 software
- double difference approach
- estimating tropospheric delays on short and long baselines (Niel model)
- cutoff angle: 3° (in case of L_3T); 10° otherwise



Scenarios for combining networks



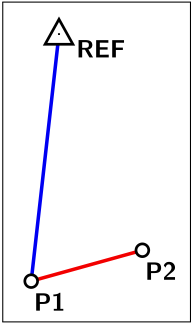
Explanations to to the scenarios

short baseline

long baseline

How to link Coordinates: Scenario 1.1 (different solution types)

Scenario 1.1 *short baseline (local stations), one station linked via long baseline*



application

- short baseline with L_1
- long baseline as L_3T (T: troposphere estimation)
- combination of normal equations systems (NEQs) of both baselines

advantages

- make use of most precise L_1 observations
- no systematic coordinate deviations driven by tropospheric modeling

disadvantages

- correlations between baselines cannot be taken into account

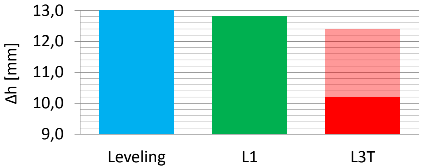
How to link Coordinates: Scenario 1.2 (single solution type)

Scenario 1.2 *short baseline (local stations) and long baseline determined with unique solution type (L_3T)*

application

- L_3T for both baselines (long and short)
- determine ΔT by comparing L_3T and L_1 solutions
- determine correction Δh_{L_3T} for station, not connected to reference station

$$\boxed{\Delta h'_{L_3T} = \Delta h_{L_3T} - \delta_U^T \cdot \Delta T}$$



L_3T := solution for up-component

L_3T := correction for up-component

advantages

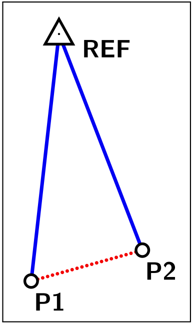
- take correlations of baselines into account

disadvantages

- **only** compensates for difference L_3T and L_3
- difference between L_1 and L_3 remains

How to link Coordinates: Scenario 2

Scenario 2 *two local stations are connected to one unique reference station via two long baselines*



application

- long baselines as L_3T
- correcting up-component values with δ_U^T (due to mathematically *apparent* height changes)
- $\delta_U^T \in [-3.5; -3]$

advantages

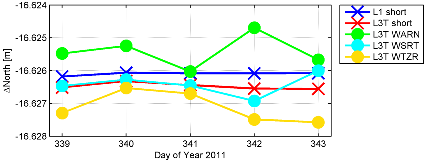
- correction δ_U^T reduces systematic deviations of L_3T
- smoothing of repeated coordinate time series

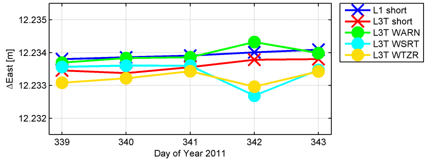
disadvantages

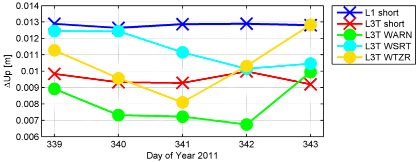
- noisier results on long baselines (w.r.t. short baseline)
- systematic offset between L_1 and L_3T on short baseline remains

Scenario 2: Baselines depending on choosen reference station

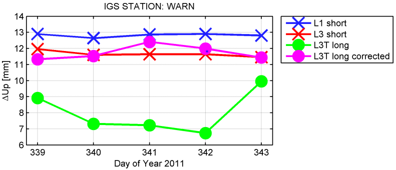
original time series

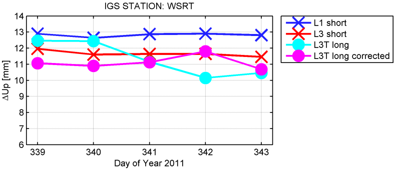


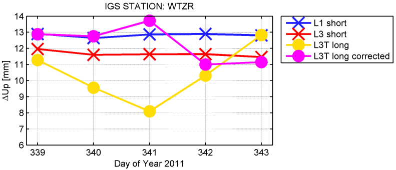




corrected time series

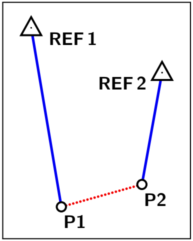






How to link Coordinates: Scenario 3

Scenario 3 *two local stations are connected to two different reference stations via two long baselines*



application

- using L_3T for both stations connected to *different* reference stations
- apparent height change in up-component cannot be repaired by height correction

advantages

- *ad hoc* or *simple* application to connect two individual GNSS-networks (*rare case*)

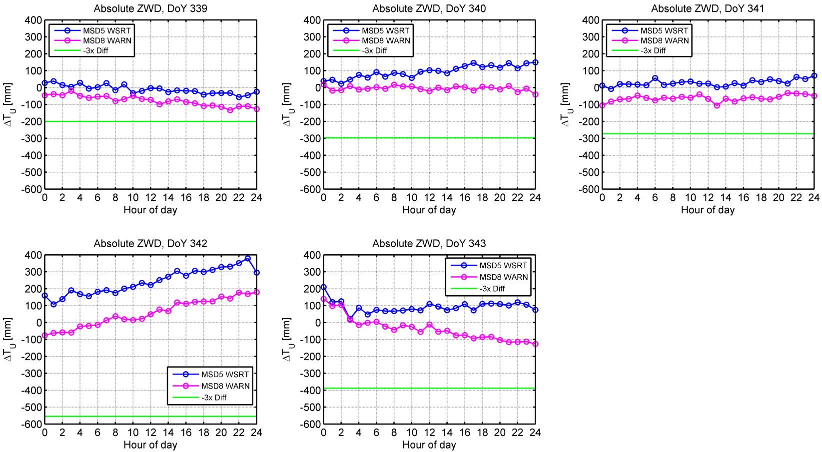
disadvantages

- individual datum of individual network (datum (S)-Transformation needed)
- correction in up-component is not applicable on troposphere parameter (similar troposphere typically not present)

Scenario 3: local baseline with different reference stations

Zenith wet delay (ZWD) for local coordinate time series and IGS stations

- WARN (Warnemünde, Germany)
- WSRT (Westerborg, Germany)



Summary | influence of troposphere on GNSS-based distance metrology

Concept of correcting influence of troposphere

1. **Scenario 1: two local stations and one connected to reference station**
   - different solution types (L_1 & L_3 / L_3T) -> applicable (currently best case!)
   - single solution type (L_3T) -> applicable with height correction, [Krawinkel et al., 2014]

2. **Scenario 2: two local stations connected to one single reference station (long baseline)**
   - applicable with height correction, [Krawinkel et al., 2014], but with noisier solution ($3\sigma_{L_1}$)
   - strongly depending on choosen reference station

3. **Scenario 3: two local stations connected to two different reference stations (long baselines)**
   - correction currently not applicable due to
     - different troposphere at individual reference stations
     - individual network datums need to be harmonized

Outlook | present activities

current and further work

- analysis of twin-stations within IGS, EPN as well as ITRF stations
- **aim:** investigate and reduce the mathematical *apparent* height change for several international network scenarios
- special focus on local tie issue to investigate **best practice workflow** for combining GNSS and other networks (terrestrial etc.)

EMRP

European Metrology Research Programme

Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

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Acknowledgement

This work is performed within the joint research project SIB60 *Surveying* of the European Metrology Research Programme (EMRP). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

References

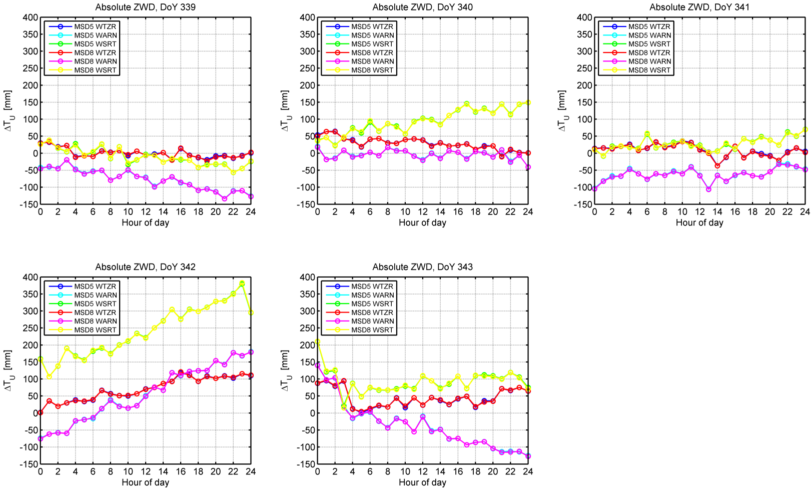
Altamimi, Z., Collilieux, X., and Metivier, L. (2011). ITRF2008: an improved solution of the international terrestrial reference frame. *Journal of Geodesy*, 85(8):457–473.

Krawinkel, T., Lindenthal, N., and Schön, S. (2014). Scheinbare Koordinatenänderungen von GPS-Referenzstationen: Einfluss von Auswertestrategien und Antennenwechseln. *Zeitschrift für Vermessungswesen*, 139:252–263.

Schön, S. (2007). Affine distortion of small GPS networks with large height differences. *GPS Solutions*, 11:107–117.

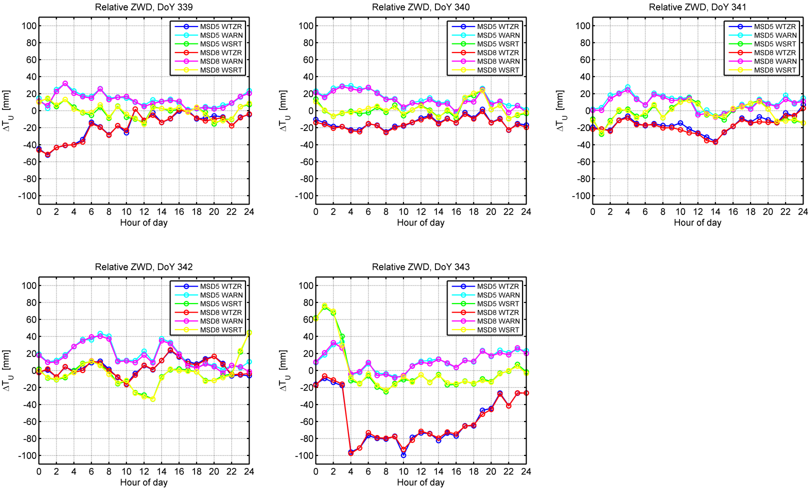
Appendix | Scenario 3: local baseline with different reference stations

Zenith wet delay (ZWD) for local coordinate time series and IGS stations



Appendix | Scenario 3: local baseline with different reference stations

Zenith wet delay (ZWD) for local coordinate time series and IGS stations



Appendix | Scenario 3: local baseline with different reference stations

Zenith wet delay (ZWD) for local coordinate time series and IGS stations